PRELIMINARY PROPOSAL FOR FY 2005 FUNDING

Title:	Survival and migration behavior of juvenile salmonids at Little Goose Dam
Study Codes:	SPE-W-04-2
Principal Investigator:	Noah S. Adams, Russell W. Perry, and Chris Peery
Project Leader(s):	Dennis W. Rondorf
Address:	U.S. Geological Survey Columbia River Research Laboratory 5501A Cook-Underwood Road Cook, WA 98605 (509) 538-2299; FAX (509) 538-2843
Submitted to:	U.S. Army Corp of Engineers Walla Walla District 201 North 3rd Avenue Walla Walla, WA 99362 (509) 527-7278
Administrative Contact:	Michele F. Beeman U.S. Geological Survey Columbia River Research Laboratory 5501A Cook-Underwood Road Cook, WA 98605 (509) 538-2299; FAX (509) 538-2843
Performance Period:	January 1, 2005 through September 30, 2005.
Date of Submission:	August 3, 2004.

Project Summary

Introduction

This proposal presents four objectives designed to meet research needs at Little Goose Dam during 2005. These objectives will distinguish between estimating survival or measuring passage behavior of juvenile salmonids because these objectives require different resources and effort. It is uncertain if regional priority and resources will support conducting research activities under all the objectives. Therefore, we designed these objectives to gain the most information at the minimum cost to the U.S. Army Corps of Engineers (COE) by integrating studies at both Lower Granite Dam (study code SBE-W-05-2) and Little Goose Dam. For example, if only passage information is desired at Little Goose Dam, all of the radio-tagged fish released at Lower Granite Dam can also be used to obtain passage information at Little Goose Dam. This approach results in a considerable cost savings ($200k - $400k) since additional transmitters would not have to be purchased for research activities at Little Goose Dam. However, if route-specific survival estimates are also desired at Little Goose Dam, then additional radio-tagged fish must be released closer to Little Goose Dam because of battery life considerations.

The COE has indicated that two treatments of differing project operations may be implemented at Little Goose Dam. However, the nature of these treatments has yet to be determined. Because we are uncertain whether different treatments will be implemented at Little Goose Dam, we have structured the proposal to provide managers the information needed to determine sample sizes whether or not treatments are implemented. To provide this information, we answered the following questions: 1) what is the precision of route-specific survival estimates that managers desire for each treatment? and 2) what is the minimum detectable difference in survival probabilities between two treatments?

Research Goals

The goal of our study is to quantify the spatial and temporal movements of juvenile salmonids and estimate their survival as they approach, pass through, and continue migration after passage through Little Goose Dam. The study is designed to obtain the following information: 1) The timing and route of passage for yearling Chinook salmon, subyearling Chinook salmon, and juvenile steelhead at Little Goose Dam relative to spill and powerhouse operations; 2) The route-specific survival of juvenile salmonids at Little Goose Dam, and 3) The effects of dam operations (e.g., varying flows, pool levels, and spill volumes) on smolt approach paths in the forebay of Little Goose Dam. This includes passage and survival estimates during two treatments of dam operations.

Objectives

Objective 1: Determine the approach path, route of passage, and tailrace egress for yearling Chinook salmon and juvenile steelhead at Little Goose Dam during two treatments of differing project operations.

Objective 2: Estimate route-specific survival of yearling Chinook salmon and juvenile steelhead passing through Little Goose Dam during two treatments of differing project operations.

Objective 3: Determine the approach path, route of passage, and tailrace egress for subyearling Chinook salmon at Little Goose Dam relative to spill and powerhouse operations.

Objective 4: Estimate route-specific survival of subyearling Chinook salmon at Little Goose Dam during two treatments of differing project operations.

Note: These study objectives meet the research needs identified in SPE-W-04-2.

Methodology

For all objectives, we propose to use radio telemetry techniques to obtain both survival and behavioral information for juvenile salmonids migrating past Little Goose Dam. Because radio-tagged fish are usually detected at high rates (>80% detection probability), radio telemetry techniques are well suited to estimate survival rates with small sample sizes and desired precision of survival estimates. PIT tag technology will be used to divert radio-tagged fish back to the river for route-specific survival estimates. We will use the route-specific survival model (RSSM) developed by Skalski et al. (2002) to estimate passage and survival probabilities for the turbines, spillway, and juvenile bypass system. In addition, using the RSSM, we will estimate the overall survival probability of dam passage and survival from release to the dam.

To provide passage and survival information at Little Goose Dam, we propose to release between 1,500 and 2,000 radio-tagged fish (per species) for each treatment of dam operation (i.e., 3,000-4,000 radio-tags for two treatments). We will release yearling Chinook salmon (*Oncorhynchus tshawytscha*), juvenile steelhead (*Oncorhynchus mykiss*), and subyearling Chinook salmon (*Oncorhynchus tshawytscha*) to quantify their migration behavior and estimate their survival rates. If survival estimates are not required, then radio-tagged fish released at Lower Granite Dam can also be used to obtain passage information at Little Goose Dam. For most passage routes, analysis suggests that this sample size will yield survival probabilities with precision of ±0.03-0.04 (±95% confidence interval) for spring migrants and ±0.04-0.05 for summer migrants. However, the fewest fish are expected to pass through the turbines, which will yield lower precision for turbine survival estimates (±95% confidence interval > 0.05).

Relevance to the Biological Opinion

The relevance of this research to the operation of the Federal Columbia River Power System and Juvenile Transportation Program is discussed in the draft Biological Opinion, July 27, 2000, action items 82 and 83.

Project Description

Background and Justification

Many sources of mortality affect populations of juvenile salmonids as they migrate from their natal streams to the ocean. As a result of passing through hydroelectric projects, juvenile salmonids can experience both direct, instantaneous mortality and indirect, delayed mortality. Direct mortality results from injury due to dam passage and indirect mortality occurs when passage through a dam increases a fish's probability of succumbing to predation, disease, or physiological stress. Many studies of the effects of dam operations on the mortality of juvenile salmonids have led to specific guidelines and management actions for operation of the Federal Columbia River Power System (NMFS 2001). However, there have been no passage and survival studies conducted at Little Goose Dam in recent years, resulting in limited information to guide future management actions at Little Goose Dam. Therefore, baseline passage and survival information is needed to ensure that Little Goose Dam meets the guidelines and management actions outlined in the NMFS 2001 Biological Opinion.

Reservoir drawdown, flow augmentation, and spill have been identified as potential means of improving the survival of juvenile salmonids, thereby assisting the recovery of threatened and endangered salmon stocks. The U.S. Army Corps of Engineers (COE) has worked with regional, state, and federal resource agencies to design and implement tests to determine whether various combinations of reservoir drawdown, flow augmentation, spill, and surface bypass would provide significant biological benefits to out-migrating smolts. A removable spillway weir is one management action being considered for implementation at Little Goose Dam.

Based on the surface bypass concept, the COE evaluated a removable spillway weir (RSW) at Lower Granite Dam during 2002 and 2003 (Plumb et al. 2003, 2004). This passage structure passed comparable percentages of fish as the current management strategy of spilling water to the 'gas cap' (i.e., BiOP spill) with just 7-8% of the total discharge. Furthermore, survival estimates of yearling Chinook salmon passing the RSW did not significantly differ from those passing through BiOP spill, indicating the RSW did not adversely affect survival relative to the current management strategy. Because the RSW may be selected as a basin-wide management strategy and installed at Little Goose Dam in the near future, baseline passage and survival information prior to RSW installation will provide useful information to aid in the design and location of a RSW at Little Goose Dam.

Using radio-telemetry and PIT techniques, we propose to estimate passage and survival rates of juvenile salmonids at Little Goose Dam. The USGS, Columbia River Research Laboratory uses radio-telemetry techniques to monitor the migration behavior of juvenile salmonids in the Snake and Columbia rivers. More recently, the Columbia River Research Laboratory has successfully used radio-telemetry techniques to estimate survival rates of juvenile salmonids in the Snake and lower Columbia rivers (Plumb et al. 2004; Counihan et al. 2002a, 2002b; Perry et al. 2003).

Many methods are available to conduct mark-recapture experiments to estimate survival rates of juvenile salmonids. Methods include passive integrated transponder (PIT) tags (Skalski et al. 1998), balloon tags (Mathur et al. 1996), and radio-telemetry (Skalski et al. 2001). Each method offers distinct advantages and limitations. A benefit of PIT tags is their small size relative to the size of the fish, but a limitation is the large sample size required to obtain high precision of survival estimates. Balloon tags allow for recovery of fish, and thus identifying the mechanisms of direct mortality. However, balloon tag studies are restricted to relatively large fish due to the tag size, and survival rates only apply to direct (1 h to 48 h) mortality. An advantage of radio-telemetry techniques is high detection probabilities, which reduces the sample size needed to obtain precise survival estimates. However, for some fish species, the size of the radio transmitter limits the size of fish that may be studied.

Project Overview

We will use radio telemetry to estimate survival probabilities over a range of spatial scales and passage routes. At the finest spatial scale, we will use the route-specific survival model (RSSM) developed by Skalski et al. (2002) to estimate passage and survival probabilities for the turbines, spillway, and juvenile bypass system. The RSSM model uses double antenna arrays (usually underwater and aerial antennas) to calculate detection and passage probabilities for a given route of passage. Given passage and detection probabilities of passage routes, the RSSM then uses the paired release-recapture models (PRRM) described by Burnham et al. (1987) and expanded on by Skalski et al. (2002) to calculate route-specific survival relative to survival rates of control groups released into the tailrace. The foundation of both of these models is based on the classical release-recapture models of Cormack (1964), Jolly (1965), and Seber (1965; CJS model). In addition to route-specific survival probabilities, these models will allow us to estimate overall survival rates through the dam, and survival from release to the dam.

To obtain an estimate of bypass survival, radio-tagged fish must be diverted into the river after being guided and passing through the juvenile bypass system. If radio-tagged fish are loaded onto barges, then we will be unable to obtain valid detections at downstream antenna arrays, and thus, unable to estimate bypass survival. Therefore, in addition to radio tags, we propose to implant PIT tags into all sample fish. Using PIT tags and "sort-by-code" technology will allow radio-tagged fish to be diverted into the tailrace after passing through the bypass system.

For quantifying migration behavior, we will monitor travel times, approach paths to Little Goose Dam, forebay movements, and routes of passage. Once fish pass the dam, we will examine their movements in the tailrace and monitor travel times downstream of the dam. To monitor fish behavior at Little Goose Dam we will use multiple aerial and underwater radio telemetry arrays. At the dam, aerial antenna arrays will be installed at the navigation wall, spillway, powerhouse, earthen dam, adult fish ladder, fish collection channel, juvenile fish bypass system, tailrace, and three detection sites below Little Goose Dam within Lower Monumental Reservoir. To obtain movement information at finer spatial scales, we will install underwater antennas on the extended-length submersible bar screens, spillway, and juvenile fish bypass system.

Current Status

At Little Goose Dam and Reservoir, past research has estimated the behavior and survival of juvenile salmonids using PIT technology (Muir et al. 2001; Smith et al. 2002, 2003). Although very useful, PIT technology is limited to providing information over a dam-to-dam spatial scale. Consequently, there is little information on fish movement patterns and survival at finer spatial scales (Venditti 2000; Plumb et al. 2004). The collection of fish passage and survival information at smaller spatial scales can help clarify location-specific factors that may affect fish passage and survival at Little Goose Dam.

Although route-specific survival estimates through Little Goose Dam have never been estimated, there is some information on fish behavior and passage through Little Goose Dam. From 1995 to 1997, Venditti et al. (2000) monitored the behavior of subyearling Chinook salmon as they migrated through Little Goose Reservoir. The authors found that travel rates of subyearling Chinook salmon decreased as fish approached the dam and that a substantial portion (10-20%) of the tagged population remained in the forebay of Little Goose Dam for 7 d or more. In addition, Venditti et al. (2000) found that the frequency of upriver movement was 3-fold greater near the dam than in the upper reservoir. During their study at Lower Granite Dam, Plumb et al. (2004) also quantified fish behavior and Fish Collection Efficiency (FCE; i.e., percent guided turbine passage) at Little Goose Dam for yearling Chinook salmon and juvenile hatchery and wild steelhead. The authors found that residence time in the forebay and frequency of fish traveling 14 km upriver of the dam was greatest for hatchery steelhead, and that FCE was 51-58% depending on species and rearing types. Although the research by Venditti et al. (2000) and Plumb et al. (2004) provided insight into the behavior of fish within the forebay of Little Goose Dam, their research was not designed to estimate survival and route-specific passage through Little Goose Dam. Consequently, there remains a limited amount of empirical information on the survival and passage of juvenile salmonids at Little Goose Dam.

Methodology

To reduce repetition of methods common to each of the four objectives, we have structured this section as follows: First, we describe tagging techniques we propose to use for implantation of transmitters into juvenile fish since these techniques are common to all objectives. Second, we combine the telemetry methods for all objectives since all will utilize the same system of antennas and receivers, and all survival estimates will be calculated using the route-specific survival model. Last, many statistical analyses and evaluation of assumptions will be common to all objectives. These methods will be presented in the section "Methods for Generating Survival Estimates".

We propose to gastrically implant radio transmitters and PIT tags into juvenile salmonids following procedures described by Adams et al. (1998a). The method of tag implantation (surgical or gastric) should not influence the survival estimates. Hockersmith et al. (2003) showed no differences in survival of PIT-tagged, gastrically-tagged, or surgically-tagged yearling Chinook salmon over long distances (about 100 km) relative to distances proposed in this study (about 50 km). Furthermore, the route-specific survival model uses a paired release design that controls for factors such as potential tagging and handling effects. We will release all fish at New York Island, about 14 km upstream of the dam.

The planned operation of the juvenile bypass facility in 2004 will necessitate using PIT tags to divert radio-tagged fish into the river to estimate survival through bypass system. During the spring and summer, all fish collected by the bypass system will be transported by barges. If radio-tagged fish are barged, we will be unable to obtain valid downstream detections and therefore, unable to estimate survival through the bypass system. We plan to integrate the PIT tag into the radio tag to eliminate double tagging of fish. PIT tags integrated with radio tags are used often to divert fish from bypasses into the river and to obtain detections of fish after their radio tags have expired (Hockersmith et al. 2003).

We will use coded radio transmitters weighing no more than 1.4 g in air for yearling Chinook salmon, 1.8 g for juvenile steelhead, and 0.85 g for subyearling Chinook salmon (Lotek Inc., Newmarket, Ontario). PIT tags weigh 0.07 g. We will restrict the size of fish used so that the combined weight of the tags represents no more than 6.5% of the fish's weight.

To estimate passage and survival probabilities with the RSSM, we will conduct daily treatment releases of radio-tagged juvenile salmon upstream of Little Goose Dam (R_t) and daily control releases in the tailrace (R_c; Figure 1). Fish will be released upstream of Little Goose Dam to allow recovery from handling stress and to reinitiate normal migration behavior. Using the RSSM, we will estimate survival rates from the release point to the dam (S_{pool}; Figure 1). Route-specific passage (Sp, By, and Tu) and detection probabilities (p_{Sp}, p_{By}, and p_{Tu}; Figure 1) will be estimated by using double detection arrays for each passage route. Double detection arrays will consist of two independent antenna systems, one underwater and one aerial system, allowing for the estimation of route specific parameters. Given these route-specific parameters, survival of fish passing through each route (S_{Sp}, S_{By}, S_{Tu}; Figure 1) will be estimated relative to the survival of control groups of fish released in the tailrace of Little Goose Dam. Given route-specific passage and survival probabilities, we will calculate the overall survival probability of dam passage.

For estimating survival, three distinct radio telemetry arrays will be installed downstream of Little Goose Dam (river kilometer, rkm 112) at the Tucannon River (rkm 100), Lyons Ferry (rkm 94), and Skookum Creek (rkm 77; Figure 3). Each array will typically consist of three telemetry fixed sites, with one located on each shore and the third located in the center of the channel. The sites in center channel will either be mounted on an anchored barge or on a U.S. Coast Guard navigation marker.

To address some of the assumptions of survival models, we will conduct a tag life study and release a small subsample of euthanized, radio-tagged fish. A tag life study will be conducted to test the assumption that all tags are functional while fish are in the study area. The tag life study will estimate the probability of a tag being at a given point in time. In the case of premature tag failure or long travel times due to low flows, data from the tag life study can be used to adjust survival estimates if tags fail prior to fish exiting the study area. A small subsample of euthanized radio-tagged fish will be released to test the assumption that radio-tag detections represent detections of only live fish (i.e., test for false positive detections). Survival estimates may be biased high if dead fish are detected.

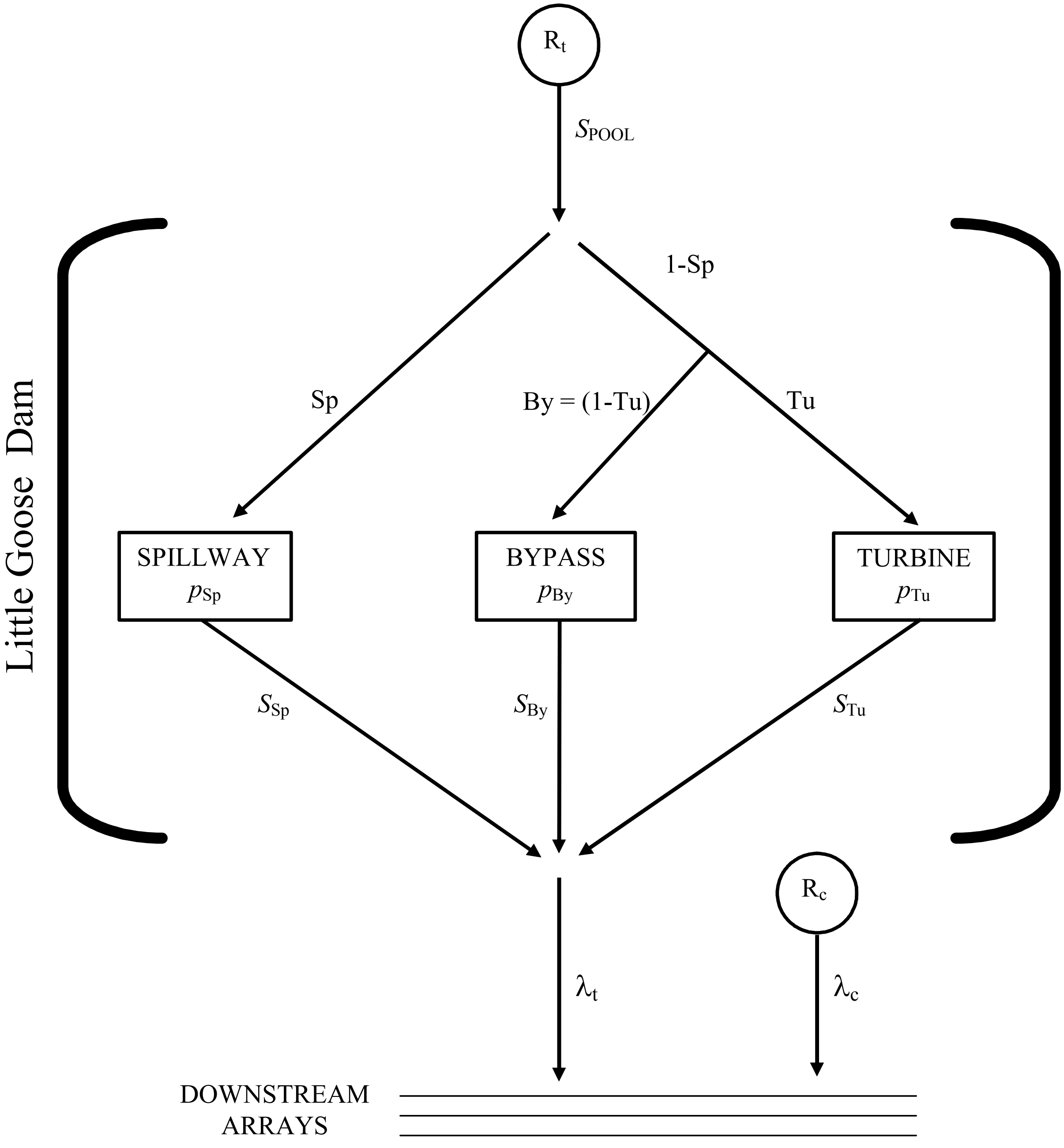

Figure 1. Schematic of route-specific survival model showing release sites, passage routes, and parameters to estimate route-specific detection, passage, and survival probabilities at McNary Dam. Shown are the treatment releases (R_t) upstream of McNary Dam, control releases in the tailrace (R_c), and estimable parameters. Estimable parameters include passage (Sp, By, and Tu), detection (p_{Sp}, p_{By}, and p_{Tu}), and survival (S_{Sp}, S_{By}, and S_{Tu}) probabilities. Lamba (λ_t, λ_c) is the joint probability of surviving and being detected by the downstream antenna arrays.

Objectives and Tasks

For survival estimates below, we calculated expected standard errors and confidence intervals of survival probabilities over a range of sample sizes. In addition to sample size, standard errors of survival probabilities are affected by detection probabilities, the magnitude of the survival probability, and the proportion of fish passing through each route. We assumed some of these parameter values and used others from Appendix D of the NMFS 2000 Biological Opinion to estimate expected standard errors. We used the paired-release recapture model to estimate standard errors because currently, software is not available to estimate standard errors with the route-specific survival model. We emphasize that the standard errors and confidence intervals presented here are specific the set of input parameters we used. These confidence intervals will change given the set of parameters we estimate from data collected during the field study. In addition, because standard errors include only the expected sampling variation, observed standard errors could be larger if survival probabilities are affected by external factors such as discharge or water temperature. Nonetheless, our objective here is to examine the sensitivity of confidence intervals to different sample sizes for each passage route. This should help identify a general range of sample sizes and differences among passage routes in the expected precision of survival estimates.

We also conducted a power analysis to estimate the detectable difference in dam survival (S_{dam}) between two treatments (using the methods of Perry et al. (2003)). We use S_{dam} for this analysis, rather than survival through a specific passage route, because too few fish will pass through each route to detect small survival differences with sufficient statistical power. In addition, differences in project operations could affect the proportion of fish passing through the available routes. Therefore, it is important to consider how changes in dam operations affect the overall survival rate of the population passing the dam, rather than just the survival rate of fish passing through a specific route.

Objective 1: Determine forebay behavior, route of passage, and tailrace egress for yearling chinook salmon and juvenile steelhead at Little Goose Dam during two treatments of differing project operations.

We propose to release radio-tagged spring migrants and monitor the forebay residence times, route of passage, and egress through the tailrace of Little Goose Dam during various spill and powerhouse operations. The proposed evaluation would be conducted during the April-June out-migration in 2005. At this time, no specific study design for implementing treatments has been proposed for this evaluation. Similar research has evaluated passage and behavior using a study design consisting of two-day treatments randomized within a 4-day blocks. These 4-day blocks served as replicates over the length of the study period. The study period was typically 40-50 days long. Until further discussion occurs, we have developed this proposal under the assumption that a similar study design will be used to evaluate the treatments at Little Goose Dam in 2005. If only passage information is required then fish released at Lower Granite Dam (between 1,000 and 1,500 radio-tagged fish per species/rearing type) can also be used to obtain passage information at Little Goose Dam. If survival estimates are also required, the sample sizes outlined under Objective 2 should be sufficient to estimate passage parameters with good precision.

Since 1996, we have used coded radio transmitters supplied by Lotek Engineering. We surgically implanted tags in both juvenile chinook salmon and steelhead at Lower Granite Dam. During our telemetry evaluations at Lower Granite Dam our tagging related mortality was about 3% in 1996, less than 1% in 1997 and 1998, and less than 1.5% from 2000 to 2003. Due to the proposed sample size for the 2005 test, we will not be able to surgically implant the tags. Instead, we will use the less labor-intensive gastric tagging method. This method has been successfully used in the lower Columbia River for the last 5 years. The coded tags we propose to implant offer several features that make them ideal for studying juvenile fish movements at Little Goose Dam. Because each tag is uniquely coded, 521 tags can broadcast on the same frequency without losing the ability to identify distinct individuals. As a result, the scan cycle of the receiver is relatively short and the probability of not detecting a fish is fairly low. Additionally, a Digital Spectrum Processor (DSP) can be used in conjunction with a receiver to scan multiple frequencies and codes simultaneously. The DSP essentially eliminates any need for a scan cycle and allows for nearly instantaneous detection of all fish within range of the antennas. We are also proposing the continued use of a relatively new data acquisitions system (Multiprotocol Integrated Telemetry Acquisition System; MITAS). The MITAS system has many advantages over the system we have used in the past (faster and multiple signal acquisition, data consolidation, real-time data views, improved system diagnostics) and should provide more complete data on fish movements in the forebay of Little Goose Dam.

Schedule of Tasks

Task 1.1: Install fixed monitoring sites on and around Little Goose Dam.

Activity 1.1.1

Install, calibrate, and test the underwater and aerial antenna arrays at Little Goose Dam.

Schedule: March through May 2005.

Activity 1.1.2

Install, calibrate, and test fixed monitoring sites above Little Goose Dam, in the tailrace of Little Goose Dam, and at the Juvenile Fish Bypass Facility

Schedule: February through March 2005.

Task 1.2: Conduct releases of yearling chinook salmon and juvenile steelhead in Little Goose Reservoir during the spring of 2005.

Activity 1.2.1

Continue to develop analytical procedures for examining radio-telemetry data. We will consult with statisticians as the Region reaches consensus on a design for the 2005 test.

Schedule: Work will continue through the 2005 field season.

Activity 1.2.2

Determine release site, number of fish per release, and time interval between releases. We tentatively propose that the release site be located at New York Island. This site appears to be far enough upriver of the dam to allow fish to recover from the stress associated with the tagging procedure, but still allowed us to have some control over when the fish arrived at the dam.

Schedule: December 2004 through January 2005.

Activity 1.2.3

Complete the necessary Endangered Species Act documentation and obtain the necessary permits and approval to work in the Snake River.

Schedule: December 2004.

Activity 1.2.4

Coordinate with appropriate agencies to sequester, implant tags, and release spring migrating smolts during the months of April, May, and June 2005 (the spring out-migration period).

Schedule: February through March 2005.

Activity 1.2.5

Monitor the movements of radio-tagged fish in the forebay and tailrace areas of Little Goose Dam.

*Schedule:*April through June 2005.

Task 1.4: Continue to develop and refine data reduction, storage, analysis, and transfer procedures.

Activity 1.4.1

The regional researchers and managers continue to request the results of these studies almost immediately after the field tests are completed. The data is vital for them to make informed management decisions regarding the operation of the Columbia River hydropower system. In response to these needs, we will continue to improve and refine our ability to report this data quickly.

*Schedule:*Complete by December 2005

Task 1.5: Explore means to improve and expand information collected during subsequent field seasons.

Activity 1.5.1

Acquire and test telemetry systems manufactured by Advanced Telemetry Systems, Lotek Engineering, and other vendors if appropriate as a means to increase the resolution and accuracy of data collected on fish movements.

Schedule: Ongoing.

Objective 2: Estimate route-specific survival of yearling Chinook salmon and juvenile steelhead passing through Little Goose Dam during two treatments of differing project operations.

To estimate standard errors and confidence intervals of survival probabilities, we assumed parameter values for the route-specific survival model (see Figure 1). We used the best available parameter estimates for yearling Chinook salmon and assumed the same values for juvenile steelhead. First, we assumed 95% of fish survived from release to Little Goose Dam (i.e., $S_{\text{pool}} = 0.95$). Next, we set detection probabilities (p) to 0.90. Based on Appendix D of the NMFS 2000 Biological Opinion, we set probabilities of turbine survival (S_{Tu}) to 0.92, spillway survival (S_{Sp}) to 1, and bypass survival to 0.99. For all reaches downstream of the dam, survival probabilities were set to 0.95 for both treatments and controls. We set the probability of passing through the spillway (Sp) to 0.27. We based this estimate on a spill efficiency of 1:1 and a 10-year average of 27% of river discharge through the spillway for the period April 1 – May 31 (excluding 2001 data because of low discharge). Last, we estimated the probability of passing the dam through the juvenile bypass system (By) based on an FGE estimate of 0.78 for Little Goose Dam from Appendix D of the NMFS 2000 Biological Opinion.

The 95% confidence intervals show the affect of sample size on precision and the difference in precision among survival probabilities (Figure 2). Turbine survival probabilities will likely have the lowest precision because the fewest fish are expected to pass through this route and turbine survival probabilities are expected to be the lowest of all available passage routes. Overall survival for all passage routes (S_{dam}) is expected to have the highest precision because this estimate incorporates the increased sample size of all passage routes. If precision of survival estimates is the primary goal, then a sample size between 1,500 and 2,000 (per treatment and species/rearing type) should yield precision of ±0.03-0.04 (±95% confidence interval) with lower precision for the turbine survival (Table 1).

For statistically comparing S_{dam} among the two treatments, we calculated the minimum detectable difference in survival over a range of sample sizes and based on four combinations of alpha, beta (power=1-beta), and a 1- or 2-tailed test. To calculate standard errors for the power analysis we assumed the same survival and passage parameters described above. We assumed S_{dam} to be the average survival of fish passing through all routes weighted by the proportion of fish passing through each route. Figure 3 allows managers to examine how a range of sample sizes affects the minimum detectable difference between treatments to determine the most appropriate sample size under a given test scenario.

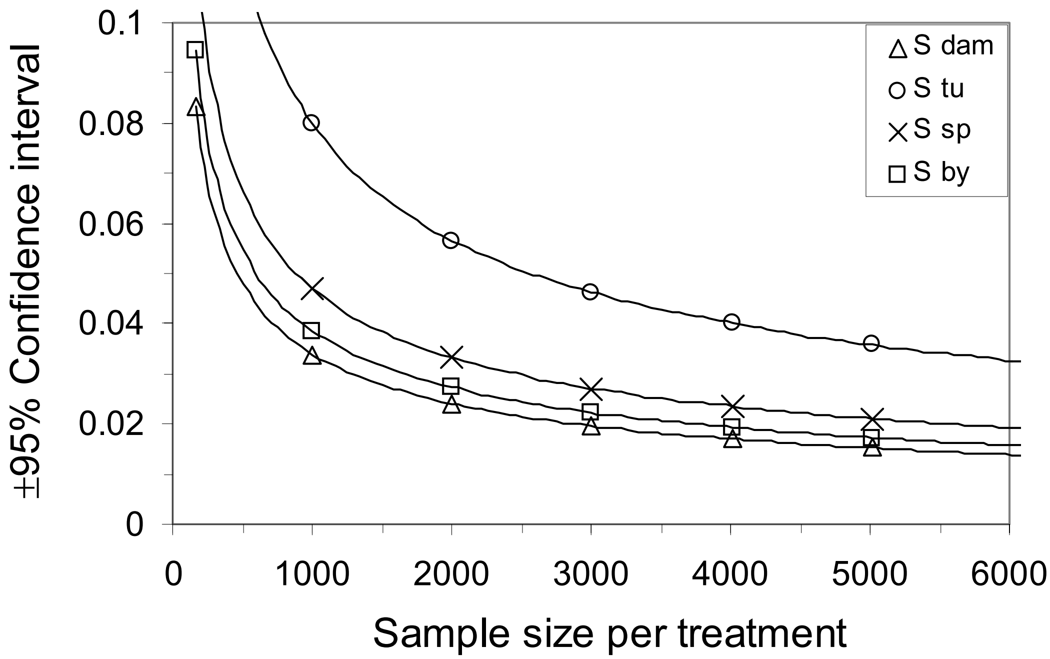

Figure 2. The effect of sample size on precision of dam survival (S_{Dam}), turbine survival (S_{Tu}), spill survival (S_{Sp}), and bypass survival (S_{By}) probabilities for spring migrants at Little Goose Dam. Sample sizes are for one treatment of dam operations and for one species/rearing type. Note: about 100 additional tags will be needed for releasing euthanized tagged fish and for conducting a tag life study.

Table 1. Sample size, expected standard error, and 95% confidence interval for route-specific survival probabilities of spring migrants. Sample sizes are for one species/rearing type and total sample size assumes two treatments of dam operations. Note: about 100 additional tags will be needed for releasing euthanized tagged fish and for conducting a tag life study.

Sample size for each treatment	Total sample size	Route	Expected sample size for each route and each treatment	Expected standard error	± 95% Confidence Interval
1500	3000	Turbine	137	0.032	0.065
		Spill	231	0.019	0.039
		Bypass	487	0.016	0.031
		Dam	855	0.014	0.028
2000	4000	Turbine	158	0.030	0.060
		Spill	422	0.015	0.031
		Bypass	560	0.014	0.027
		Dam	1140	0.012	0.024

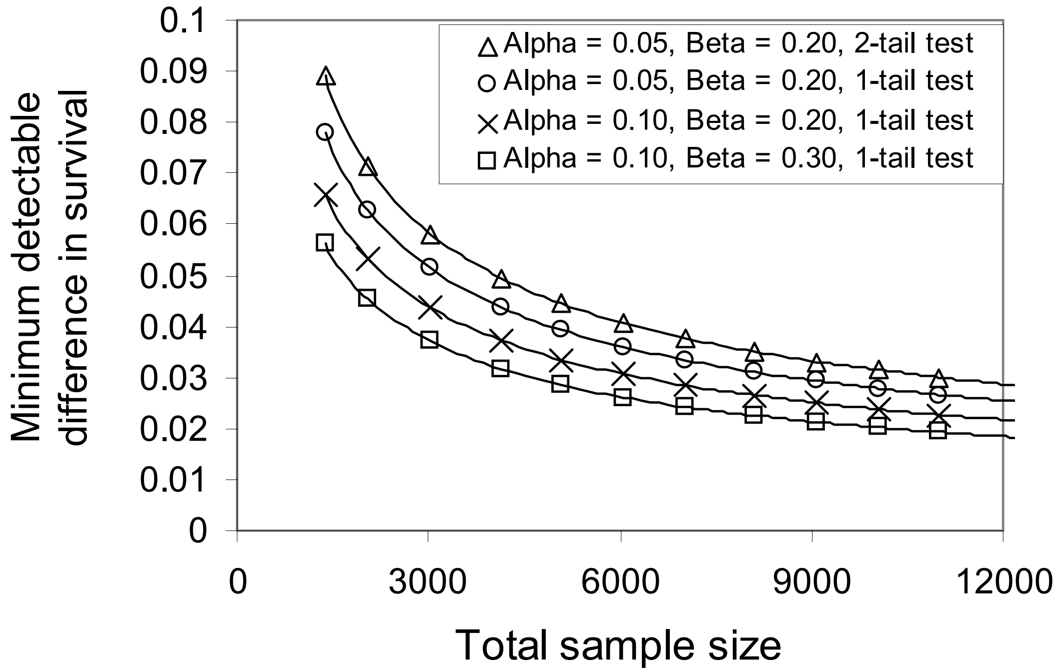

Figure 3. The minimum detectable difference in survival probabilities (S_{dam}) between two treatments for a range of sample sizes and test scenarios for spring migrants at Little Goose Dam.

Schedule of Tasks
Note: Many of the tasks for Objective 2 will be completed under Objective 1. To minimize repetition, we include only additional tasks that will be needed to achieve Objective 2.

Task 2.1: Conduct control releases of yearling Chinook salmon and juvenile steelhead in the tailrace of Little Goose Dam during the spring of 2005.

Activity 2.1.1

Develop analytical procedures for determining route-specific survival estimates for yearling Chinook salmon and juvenile steelhead. Since our laboratory has extensive experience conducting survival studies using radio telemetry data, much of the groundwork has been completed to accomplish this task. We will consult with statisticians prior to finalizing survival estimates tasks and objectives.

Schedule: November 2004.

Activity 2.1.2

Install and test additional monitoring sites downstream of Little Goose Dam. These additional sites will be needed below the dam to collect the necessary capture history data inherent to generating survival estimates.

Schedule: February through March 2005.

Activity 2.1.3

Monitor the movements of radio-tagged fish released above and below Little Goose Dam to estimate route specific survival of yearling Chinook salmon and juvenile steelhead.

*Schedule:*April-May 2005.

Task 2.2: Estimate false-positive detection rates for radio-tagged yearling Chinook salmon and juvenile steelhead released in the tailrace of Little Goose Dam.

Activity 2.2.1

Release radio-tagged yearling Chinook salmon that have been euthanized to estimate the probability of false-positive detections.

Schedule: Apr. – May, 2005

Task 2.3: Compile and proof fish release data, telemetry data, and environmental data using standard database and statistical analysis software.

Activity 2.3.1:

Compile fish release data, telemetry data, and environmental data into standard database and statistical analysis software.

Schedule: Sept. – Oct., 2005

Activity 2.3.2

Proof telemetry data and conduct standardized data quality control/assurance procedures necessary for survival analysis.

Schedule: Sept. – Oct., 2005

Activity 2.5.3

Generate detection-history matrices from the proofed telemetry data in preparation for analysis.

Schedule: Sept.– Oct., 2005

Task 2.4: Calculate passage, detection, and survival probabilities using the route-specific survival model. Examine how survival estimates vary with environmental covariates.

Activity 2.6.1

Test validity of model assumptions.

Schedule: Oct. – Nov., 2005

Activity 2.6.2

Model the survival and capture probabilities using User Specified Estimation Routine (USER).

Schedule: Oct. – Nov., 2005

Objective 3: Determine forebay behavior, route of passage, and tailrace egress for subyearling Chinook salmon at Little Goose Dam relative to spill and powerhouse operations.

We propose to release radio-tagged subyearling Chinook salmon and monitor forebay residence times, route of passage, and egress through the tailrace of Little Goose Dam during various spill and powerhouse operations. The proposed evaluation would be conducted during the July-August out-migration in 2005. At this time, no specific study design for implementing treatments has been proposed for this evaluation. If only passage information is required then fish released at Lower Granite Dam (between 1,000 and 1,500 radio-tagged fish per species/rearing type) can also be used to obtain passage information at Little Goose Dam. If survival estimates are also required, the sample sizes outlined under Objective 3 should be sufficient to estimate passage parameters with good precision.

Schedule of Task
Note: Many of the tasks for Objective 3 will be completed under previous objectives. To minimize repetition, we include only additional tasks that will be needed to achieve Objective 3.

Task 3.1: Conduct releases of subyearling Chinook salmon in Little Goose Reservoir during the summer of 2005.

Activity 3.3.3
Complete the necessary Endangered Species Act documentation and obtain the necessary permits and approval to work in the Snake River.
Schedule: December 2004.

Activity 3.3.5
Monitor the movements of radio-tagged fish in the forebay and tailrace of Little Goose Dam relative to treatment tests.
Schedule: June through July 2005.

Objective 4: Estimate route-specific survival of subyearling Chinook salmon at Little Goose Dam during two treatments of differing project operations.

To estimate standard errors and confidence intervals of survival probabilities, we assumed parameter values for the route-specific survival model (see Figure 1). We used the best available parameter estimates for subyearling Chinook salmon and assumed the same values for juvenile steelhead. First, we assumed 90% of fish survived from release to Little Goose Dam (i.e., $S_{\text{pool}} = 0.90$). Next, we set detection probabilities (p) to 0.85, about 0.05 lower than detection probabilities we typically obtain for spring migrants (Plumb et al. 2004). Based on Appendix D of the NMFS 2000 Biological Opinion, we set probabilities of turbine survival (S_{Tu}) to 0.90, spillway survival (S_{Sp}) to 0.98, and bypass survival to 0.98. For all reaches downstream of the dam, survival probabilities were set to 0.90 for both treatments and controls. Next, we assumed there would be no spill during the 2005 evaluation at Little Goose Dam. Last, we estimated the probability of passing the dam through the juvenile bypass system (By) based on an FGE estimate of 0.53 for Little Goose Dam from Appendix D of the NMFS 2000 Biological Opinion.

The 95% confidence intervals show the affect of sample size on precision and the difference in precision among survival probabilities (Figure 4). Turbine survival probabilities will likely have the lowest precision because the fewest fish are expected to pass through this route and turbine survival probabilities are expected to be the lowest of all available passage routes. Overall survival for all passage routes (S_{dam}) is expected to have the highest precision because this estimate incorporates the increased sample size of all passage routes. If precision of survival estimates is the primary goal, then a sample size between 1,500 and 2,000 (per treatment) should yield precision of ±0.03-0.04 (±95% confidence interval) with lower precision for the turbine survival (Table 2).

For statistically comparing S_{dam} among the two treatments, we calculated the minimum detectable difference in survival over a range of sample sizes and based on four combinations of alpha, beta (power=1-beta), and a 1- or 2-tailed test. To calculate standard errors for the power analysis we assumed the same survival and passage parameters described above. We assumed S_{dam} to be the average survival of fish passing through all routes weighted by the proportion of fish passing through each route. Figure 5 allows managers to examine how a range of sample sizes affects the minimum detectable difference between treatments to determine the most appropriate sample size under a given test scenario.

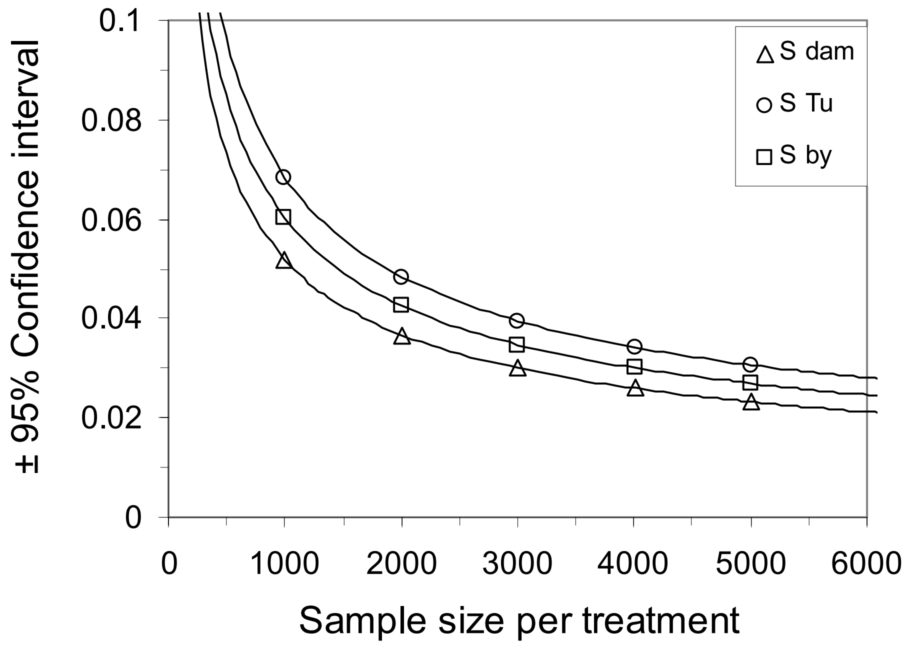

Figure 4. The effect of sample size on precision of dam survival (S_{Dam}), turbine survival (S_{Tu}), spill survival (S_{Sp}), and bypass survival (S_{By}) probabilities for subyearling Chinook salmon at Little Goose Dam. Sample sizes are for one treatment of dam operations. Note: about 100 additional tags will be needed for releasing euthanized tagged fish and for conducting a tag life study.

Table 2. Sample size, expected standard error, and 95% confidence interval for route-specific survival probabilities of subyearling Chinook salmon. Total sample size assumes two treatments of dam operations. Note: about 100 additional tags will be needed for releasing euthanized tagged fish and for conducting a tag life study.

Sample size for each treatment	Total sample size	Route	Expected sample size for each route and each treatment	Expected standard error	± 95% Confidence Interval
1500	3000	Turbine	381	0.028	0.056
		Spill	0	NA	NA
		Bypass	489	0.024	0.050
		Dam	810	0.021	0.043
2000	4000	Turbine	518	0.024	0.048
		Spill	0	NA	NA
		Bypass	562	0.021	0.043
		Dam	1080	0.018	0.037

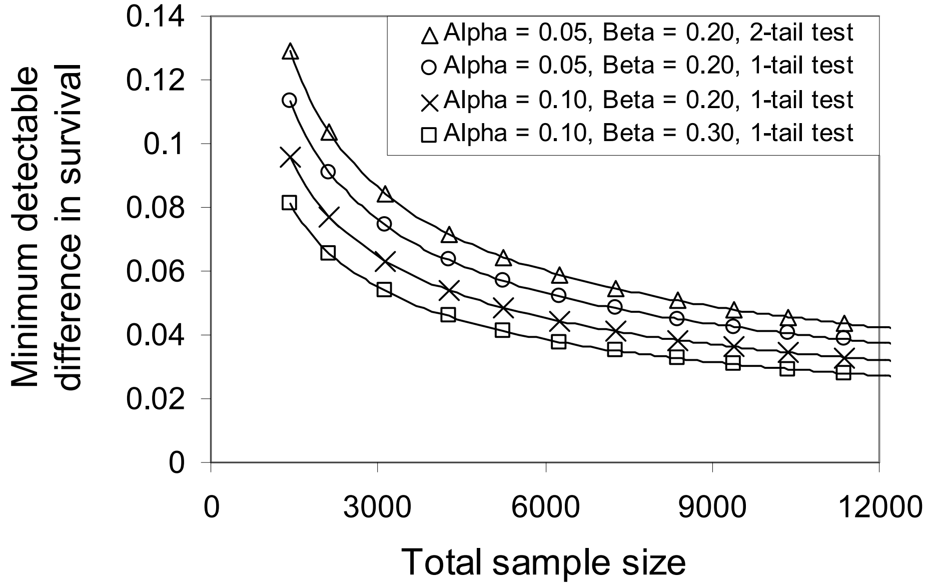

Figure 5. The minimum detectable difference in survival probabilities (S_{dam}) between two treatments for a range of sample sizes and test scenarios for subyearling Chinook salmon at Little Goose Dam.

Schedule of Tasks
Note: Many of the tasks for Objective 4 will be completed under Objective 3. To minimize repetition, we include only additional tasks that will be needed to achieve Objective 4.

Task 4.1: Conduct releases of subyearling Chinook salmon in the forebay and tailrace of Little Goose Dam during the summer of 2005.

Activity 4.1.1

Develop analytical procedures for determining route-specific survival estimates for subyearling Chinook salmon. Since our laboratory has extensive experience conducting survival studies using radio telemetry data, much of the groundwork has been completed to accomplish this task. We will consult with statisticians prior to finalizing survival estimates tasks and objectives.

Schedule: November 2004.

Activity 4.1.2

Install and test additional monitoring sites downstream of Little Goose Dam. These additional sites will be needed below the dam to collect the necessary capture history data inherent to generating survival estimates.

Schedule: February through March 2005.

Activity 4.1.3

Monitor the movements of radio-tagged fish released above and below Little Goose Dam to estimate route specific survival of subyearling Chinook salmon.

*Schedule:*July-August 2005.

Task 4.2: Estimate false-positive detection rates for radio-tagged subyearling Chinook salmon released in the tailrace of Little Goose Dam.

Activity 4.2.1

Release radio-tagged subyearling Chinook salmon that have been euthanized to estimate the probability of false-positive detections.

Schedule: July-August 2005.

Task 4.3: Compile and proof fish release data, telemetry data, and environmental data using standard database and statistical analysis software.

Activity 4.3.1:

Compile fish release data, telemetry data, and environmental data into standard database and statistical analysis software.

Schedule: Sept. – Oct., 2005

Activity 4.3.2

Proof telemetry data and conduct standardized data quality control/assurance procedures necessary for survival analysis.

Schedule: Sept. – Oct., 2005

Activity 4.5.3

Generate detection-history matrices from the proofed telemetry data in preparation for analysis.

Schedule: Sept.– Oct., 2005

Taskb 4.4: Calculate passage, detection, and survival probabilities using the route-specific survival model. Examine how survival estimates vary with environmental covariates.

Activity 4.6.1

Test validity of model assumptions.

Schedule: Oct. – Nov., 2005

Activity 4.6.2

Model the survival and capture probabilities using USER.

Schedule: Oct. – Nov., 2005

Methods for generating survival estimates

We will use the route-specific survival model (Skalski et al. 2002) to estimate passage, detection, and survival probabilities from the replicated paired releases of radio-tagged yearling and subyearling Chinook salmon and juvenile steelhead. The foundation of this model is based on the classical single release-recapture models of Cormack (1964), Jolly (1965), and Seber (1965; CJS model) and the paired release-recapture model of Burnham et al. (1987). Here, we discuss the 11 assumptions of the route-specific survival model and briefly describe how detection histories are used to estimate passage, survival, and detection probabilities. Readers can refer to Skalski et al. (2002) for detailed methods on estimating parameters of the route specific-survival model.

Detection histories of each fish form the basis of CJS models and allow for the estimation of passage, survival, and detection probabilities. In general, survival and detection probabilities are estimated by:

1) Creating detection histories for each fish.
2) Estimating the probability of each possible detection history from the number of fish with that detection history (i.e., from the observed frequencies of each detection history).
3) Using maximum likelihood theory to find parameter estimates of passage (*Sp*, *By*, *Tu*), survival (S_i), and detection (p_i) probabilities that were most likely, given the observed data set of detection histories.

We will use the USER (User Specified Estimation Routine) software package to estimate parameters of the route-specific survival model (http://www.cqs.washington.edu/paramEst/USER). To prepare the data for input into USER, records for each fish will be summarized into detection histories to indicate whether a fish was detected at each downstream telemetry array. Detection histories are composed of '1's, which indicated a fish was detected at an array, and '0's, indicating the fish was not detected. For example, the detection history '011' means that a fish was not detected at telemetry array 1 (0), but was subsequently detected at arrays 2 and 3 (11).

Each unique detection history has a probability of occurrence that can be completely specified by 1) the probability that a fish survived (S) through reach i, S_i, and 2) the probability of detection (p) at array i, p_i. For example, if a fish was detected at an array then it must have survived through the preceding reach. Thus, the probability of this event is the joint probability that it survived and was detected, $S_i p_i$. However, if a fish was not detected at an array then two possibilities arise, 1) the fish died ($1-S_i$, the probability of not surviving), or 2) the fish survived but was not detected $S_i(1-p_i)$, the joint probability of surviving and not being detected. For the detection history 011, we can rule out the possibility that the fish died in reach 1 because it was subsequently detected at arrays 2 and 3. Therefore, the probability of detection history 011 can be specified as $S_1(1-p_1)\, S_2 p_2\, S_3 p_3$. Explicitly stated, the probability of detection history 011 is the joint probability that this fish survived through reach 1 and was not detected at array 1, survived through reach 2 and was detected at array 2, and survived through reach 3 and was detected at array 3. The probability function of each unique detection history can be specified in this fashion.

The expected probability of each detection history is then estimated from the observed frequencies of fish with that detection history. Given the expected probability of each detection history and its probability function in terms of S_i and p_i, maximum likelihood methods will be used to find the combination of S_i and p_i that were most likely to occur, given the data set of detection histories. The maximum likelihood function to be maximized is simply the joint probability of all possible detection histories. Further details on the maximum likelihood methods for estimating survival and detection probabilities, including estimation of theoretical variances, can be found in Burnham et al. (1987), Lebreton et al. (1992), and Skalski et al. (2002).

Passage, survival, and detection probabilities from the route-specific survival model are subject to 11 assumptions. Seven of these assumptions apply to CJS models, two apply to the paired release model, and two apply specifically to the route-specific survival model. For CJS models, these assumptions relate to inferences to the population of interest, error in interpreting radio signals, and statistical fit of the data to the model's structure:

1) Tagged individuals are representative of the population of interest. For example, if the target population is subyearling Chinook salmon then the sample of tagged fish should be drawn from that population.
2) Survival and detection probabilities of tagged fish are the same as that of untagged fish. For example, the tagging procedures or sampling of fish at downstream telemetry arrays should not influence survival or detection probabilities. If the tag negatively affects survival, then single-reach estimates of survival rates will be biased accordingly.
3) All sampling events are instantaneous. That is, sampling should take place over a short distance relative to the distance between telemetry arrays so that the chance of mortality at a telemetry array is minimized. This assumption is necessary to correctly attribute mortality to a specific reach. This assumption is usually satisfied by the location of telemetry arrays and the downstream migration rates of juvenile salmonids.
4) The fate of each tagged fish is independent of the fate of other tagged fish. In other words, survival or mortality of one fish has no effect on that of others.
5) The prior detection history of a tagged fish has no effect on its subsequent survival. This assumption could be violated if there are portions of the river that are not monitored for tagged fish. For example, for PIT-tagged fish some fish may repeatedly pass through fish bypasses where PIT tag readers are located, whereas other fish may consistently pass through spillways, which are not monitored. If fish passing through these routes have different survival rates, then this assumption could be violated. For radio telemetry, this assumption is usually satisfied by the passive nature of detecting radio tags, by monitoring all routes of passage at a dam, and by monitoring the entire channel cross-section of the river.
6) All tagged fish alive at a sampling location have the same detection probability. This assumption could also be violated as described in assumption 5, but is usually satisfied with radio telemetry by monitoring the entire channel cross-section.

7) All tags are correctly identified and the status of tagged fish (i.e., alive or dead) is known without error. This assumes fish do not lose their tags and that the tag is functioning while the fish is in the study area. Additionally, this assumes that all detections are of live fish and that dead fish are not detected and interpreted as live (i.e., false positive detections). We tested this assumption by releasing a sample of euthanized tagged fish to estimate the probability of false positive detections.

We will formally test assumptions 5 and 6 using χ^2 Goodness of Fit tests known as Test 2 and Test 3 (Burnham et al. 1987). In addition, the pooled results of Test 2 and Test 3 represent an overall test of how well the CJS model fits the data. Both Test 2 and 3 are implemented as a series of contingency tables. Test 2 is informally known as the "recapture test" because it assesses whether detection at an upstream array affects detections at subsequent downstream arrays (assumption 6). Test 3 is known as the "survival test" because it assesses assumption 5 that fish alive at array i have the same probability of surviving to array i+1.

Two additional assumptions apply to the paired release-recapture model:

8) Survival for the treatment group (R_t) from its release point to the release point of control group is conditionally dependent on survival of the control group (R_c) from its release point to the first downstream telemetry array (S_{c1}).
9) Survival is equal for R_t and R_c between the release point of R_c and the first downstream telemetry array.

These assumptions imply that effects of the treatment on survival occur in the first reach only and that delayed mortality due to the treatment is not expressed below the release point of the control group. These assumptions can be satisfied if the two groups (R_t and R_c) are mixed during their downstream migration, suggesting that factors influencing survival are similar among the two release groups. However, these assumptions may also be satisfied if factors affecting survival are stable over the course of migration. To test whether paired release groups were mixed we used Rx C contingency tables where the rows (R) represent treatment and control groups and the columns (C) are the day of arrival at the downstream array. Tests of mixing were performed for each downstream array at the α=0.10 level and were adjusted using the Dunn-Šidák method (Sokal and Rohlf 1981) to control the experiment-wise Type I error rate at 0.10. Last, two additional assumptions apply to the route-specific survival model:

10) Passage routes of radio-tagged fish are known without error. This assumption can be satisfied by strategic placement of antenna arrays to avoid overlap that could result in assignment of fish to the wrong passage route. In cases where passage routes cannot be determined, the radio-tagged fish will be right-censored to it's last known location to avoid estimation bias.
11) Detection in the primary and secondary antenna arrays within a passage route are independent. This assumption will be fulfilled by having primary and secondary arrays on different receiver systems and by having the detection field for one array encompass the entire passage route.

Facilities and Equipment

Although some of the special or expensive equipment or services for the proposed study have been purchased during previous years of this study, there is a need for additional equipment. The purchase of the radio transmitters will perhaps be the most significant purchase for the proposed study. The coded radio transmitters manufactured by Lotek Engineering cost about $195.00 each.

Divers will be needed to assist in testing and repair of existing underwater antennas on the antennas on and around the RSW and BGS. At this time, we are unsure of the expense involved in these activities.

The USGS operates the Columbia River Research Laboratory that includes research boats, vehicles, office space, and laboratory facilities to conduct this study. Boats will be operated at cost with no additional lease cost to the project. Only department of Interior certified boat operators trained in CPR and First Aid will operate boats. In order to meet U.S. Coast Guard standards boats will be inspected by a third party. Furthermore, USGS will provide a quality control system consistent with the Good Laboratory Practices Act.

Other resources include:

-A selection of 30 boats up to 30 feet in length for work on the river.

-Two 2700 square foot storage facilities with a shop.

-4000 square foot wet lab facility.

-A local computer network integrating state-of-the-art GIS capabilities.

-A technical staff of 60-100 fishery biologists, ecologists, and GIS specialists.

-An office and analytical laboratory in a 15,000 square foot facility.

Impacts

<u>Impacts to other researchers</u>

Because we will be using radio-telemetry technology to study the movements of the test fish, there is a great potential for interference with other studies that use the same technology. Other studies using radio tags with the same frequencies may cause interference and could cause the loss of data that would otherwise be collected. During 1994, 1995, and 1996 our ability to collect data was compromised due to radio interference caused by other researchers. An extensive coordination effort throughout the basin allowed us to minimize this problem during 1997-1998. In conjunction with coded tag manufacturers we were able to incorporate radio tags that operated on a unique frequency used only by USGS scientists. During the 2000-2001 study periods we used these modified radio tag frequencies to reduce multiple signal collisions and eliminate unwanted detections (of fish released by other researchers), and therefore increased overall data integrity. This unique tag frequency will be used during the 2005 evaluation.

<u>Impacts to the Little Goose Project</u>

Pre-season installation of equipment will start in February 2005 and continue through May 2005. The equipment will be in use through the end July 2005. We are capable of installing most of the necessary equipment for the aerial arrays, and the impact to the Little Goose project should be minimal. However, we are not equipped to repair and install all of the underwater antennas at the turbine intakes and Extended Length Barrier Screens. At this stage in the development of the 2005 study design, the impacts to the Little Goose Project, and the assistance we might require from COE personnel is as follows:

Underwater antennas on spillway -- We will require divers to repair and install underwater antennas on the spillway. Turbine outages and spill gate closures must be in effect during diving activities. As a result, this work must be coordinated with the Little Goose project and should be completed prior to increased flows in the Snake River. Perhaps the most effective way to meet all the diving needs is to have all the work covered in one contract that is awarded by the COE.

Underwater antennas on Extended Length Bar Screens-- We will need the assistance of Little Goose Project personnel to raise and lower each screen during the repair and reinstallation of underwater antennas on the ELBS. Re-installation of the ELBS telemetry arrays is dependent on the work of numerous other contractors, and therefore a more specific schedule is difficult to estimate.

Collaborative Arrangements and Sub-Contracts

Some of the labor needed to complete the activities outlined in this proposal may be furnished through a sub-contract with a labor service provider.

List of Key Personnel and Project Duties

Personnel	Organization	Project Duties
Dennis Rondorf	BRD	Project Leader
Noah Adams	BRD	Principal Investigator
Russell Perry	BRD	Co-Principal Investigator
Chris Peery	University of Idaho	Co-Principal Investigator

Technology Transfer

The data we propose to collect during the 2005 season will provide detailed information on the movements and passage routes of juvenile salmonids at Little Goose Dam relative to spill and powerhouse operations. We plan to transfer information obtained from our analysis in the manners listed below. Once this information is transferred, it will be used to make decisions relative to operation of the Federal Columbia River Power System and Juvenile Transportation Program as discussed in the draft Biological Opinion, July 27, 2000, 9.6.1.4.2, page 9-69. In addition, the information will be used by other federal and state agencies, Indian Tribes, and the public to make management decisions to aid in the recovery of threatened and endangered populations of salmon in the Columbia Basin.

1. Preliminary reports to the Army Corps of Engineers. A preliminary report of our findings from the analysis will be submitted by November 1, 2005.

2. Presentation to the Anadromous Fish Evaluation Program (AFEP) in November 2005, and presentation to fisheries agencies, tribes, and the public at the Annual Research Review, 2005.

3. Expected draft report for 2005 by February 1, 2006 and final report by May 31, 2006.

4. Presentations to the Army Corps of Engineers staff and study review groups.

5. Presentations at professional meetings (i.e., American Fisheries Society) and publication of information in peer reviewed journals.

References

Adams, N.S., D.W. Rondorf, S.D. Evans, J.E. Kelly, and R.W. Perry. 1998a. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences. 55: 781-787.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998b. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile chinook salmon. Transactions of the American Fisheries Society 127: 128-136.

Burnham, K.P., D.R. Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival estimates based on release-recapture. American Fisheries Society Monograph No. 5. Baltimore, Maryland.

Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. Biometrika 51:429-438.

Counihan, T.D., G.S. Holmberg, J.H. Petersen. 2002a. Survival estimates of migrant juvenile salmonids in the Columbia River through John Day Dam using radio-telemetry, 2002. Draft final annual report of research by U.S. Geological Survey to the US Army Corps of Engineers. Contract No. W66QKZ20384546. Portland, Oregon.

Hockersmith, E.E., W.D. Muir, S.G. Smith, B.P. Sanford, R.W. Perry, N.S. Adams, and D.W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling chinook salmon in the Snake and Columbia rivers. North American Journal of Fisheries Management. 23: 404-413.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52:225-247.

Leberton, J.D., K.P. Burnham, J. Clobert, and D. R. Anderson. 1992. Modeling survival and testing biological hypotheses: using marked animals: A unified approach. Ecological Monographs 62:67-118.

Mathur, D., P.G. Heisey, E.T. Euston, and J.R. Skalski. 1996. Turbine passage survival estimation for chinook salmon smolts (*Oncorhynchus tshawytscha*) at a large dam on the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences. 53: 542-549.

Muir, W. D., S. G. Smith, J. G. Williams, and E. E. Hockersmith. 2001. Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

National Marine Fisheries Service (NMFS). 2001. Biological Opinion. Reinitiation of consultation on operationf of the Federal Columbia River Power System, including the Juvenile Fish Transportation Program, and 19 Burea of Reclamation Projects in the Columbia Basin. Northwest Region.

Perry, R.W., S.D. Fielding, A.C. Cochran, J.L. Schei, J.M. Sprando, G.T. George, N.S. Adams, and D.W. Rondorf. 2003. Turbine survival and migration behavior of subyearling Chinook salmon at McNary Dam, 2003. Draft Annual Report by the U. S. Geological Survey to the U.S. Department of Energy, Bonneville Power Administration, Contract 00014243, Portland, Oregon.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, J. M. Sprando, G. T. George, R.W. Perry, N. S. Adams and D. W. Rondorf. 2004. Behavior of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2002. Annual Report by the U. S. Geological Survey to the U. S. Army Corps of Engineers, contract W68SBV00104592, Walla Walla, Washington.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, A. D. Cochran, T. K. Nation, J. M. Sprando, J. L. Schei, R. W. Perry, and N. S. Adams. 2004. Behavior of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Annual Report by the U. S. Geological Survey to the U. S. Army Corps of Engineers, contract W68SBV00104592, Walla Walla, Washington.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J.R., S.G. Smith, R.N. Iwamoto, J.G. Williams, and A. Hoffman. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia rivers. Canadian Journal of Fisheries and Aquatic Sciences. 55: 1484-1493.

Skalski, J.R., J. Lady, R. Townsend, A.E. Giorgi, J.R. Stevenson, C.M. Peven, and R.D. McDonald. 2001. Estimating in-river survival of migrating salmonid smolts using radiotelemetry. Canadian Journal of Fisheries and Aquatic Sciences. 58: 1987-1997.

Skalski, J.R., R. Townsend, J. Lady, A.E. Giorgi, J.R. Stevenson, and R.D. McDonald. 2002. Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radiotelemetry studies. Canadian Journal of Fisheries and Aquatic Sciences. 59: 1385-1393.

Smith, S. G., W. D. Muir, J. G. Williams, and J. R. Skalski. 2002. Factors associated with travel time and survival of migrant yearling Chinook salmon and steelhead in the lower Snake River. North American Journal of Fisheries Management 22:385-405.

Smith, S. G., W. D. Muir, E. E. Hockersmith, R. J. Graves, C. V. Ross, W. P. Connor, B. D. Arnsberg. 2003. Influence of river conditions on survival and travel time of Snake River subyearling fall Chinook salmon. North American Journal of Fisheries Management 23:939-961.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry, Second Edition, W. H. Freeman and Company, San Francisco.

Venditti, D. A., D. W. Rondorf, and J. M. Kraut. 2000. Migratory behavior and forebay delay of radio-tagged juvenile fall Chinook salmon in a lower Snake River impoundment. North American Journal of Fisheries Management 20:41-52.